Adult emergency resuscitative thoracotomy: A Western Trauma Association clinical decisions algorithm

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KEY WORDS: Resuscitative thoracotomy; algorithm; traumatic arrest; hemorrhagic shock; Western Trauma Association.

This is a recommended evaluation and management algorithm from the Western Trauma Association (WTA) Algorithms Committee addressing the management of adult trauma patients who arrive postinjury in extremis and are considered for emergency resuscitative thoracotomy (ERT). To date, there are no published prospective randomized controlled clinical trials that have generated class I data on the topic of selection for ERT, and there are unlikely to be any given ethical considerations. These recommendations are based on published prospective and retrospective cohort and multicenter registry studies, systematic reviews and meta-analyses, and expert opinion of WTA members. The WTA algorithms are drafted by the Algorithms Committee with the final algorithm the result of an iterative process including initial review and revision by the committee members, presentation to the full WTA membership at the annual meeting for active discussion commentary and suggestions, followed by final revisions based on input received during and after the meeting.

Since its reintroduction to clinical practice in the 1960s, ERT has been widely adopted to salvage select trauma patients who present with profound shock and cardiac arrest refractory to resuscitation measures, and refinements have been made to define which patients are most likely to benefit from the procedure.[1–5] Wide variability is seen in survival rates based on mechanism of injury, anatomic injury pattern, degree of physiologic derangement, presence and duration of arrest, and signs of life (SOL) on presentation to the hospital. Inappropriate utilization of the procedure may lead to significant societal burden and cost, including salvage of the neurologically devastated, diversion of resources from other patients, consumption of blood products, utilization of operating room and hospital resources, and exposure of health care workers to injury and blood-borne pathogens.[4,6–9] Since the publication of the WTA Resuscitative Thoracotomy Guideline in 2012, prospective and retrospective series using national registries, systematic reviews and meta-analyses, novel research into components of resuscitation and evaluation of individual SOL, and a national guideline from the Eastern Association for the Surgery of Trauma (EAST) on patient selection for ERT that inform updates to the algorithm have been published.[5,8]

This algorithm (Fig. 1) and procedure guide (Fig. 2) represent a reasonable approach to the assessment and management of the adult trauma patient who may benefit from ERT. They contain lettered annotations that refer to corresponding segments within this article. The supporting text is intended to provide the rationale for the steps in the algorithm and procedure guide with available evidence, as well as highlight areas of controversy and knowledge gaps that will benefit from additional research. In the algorithm

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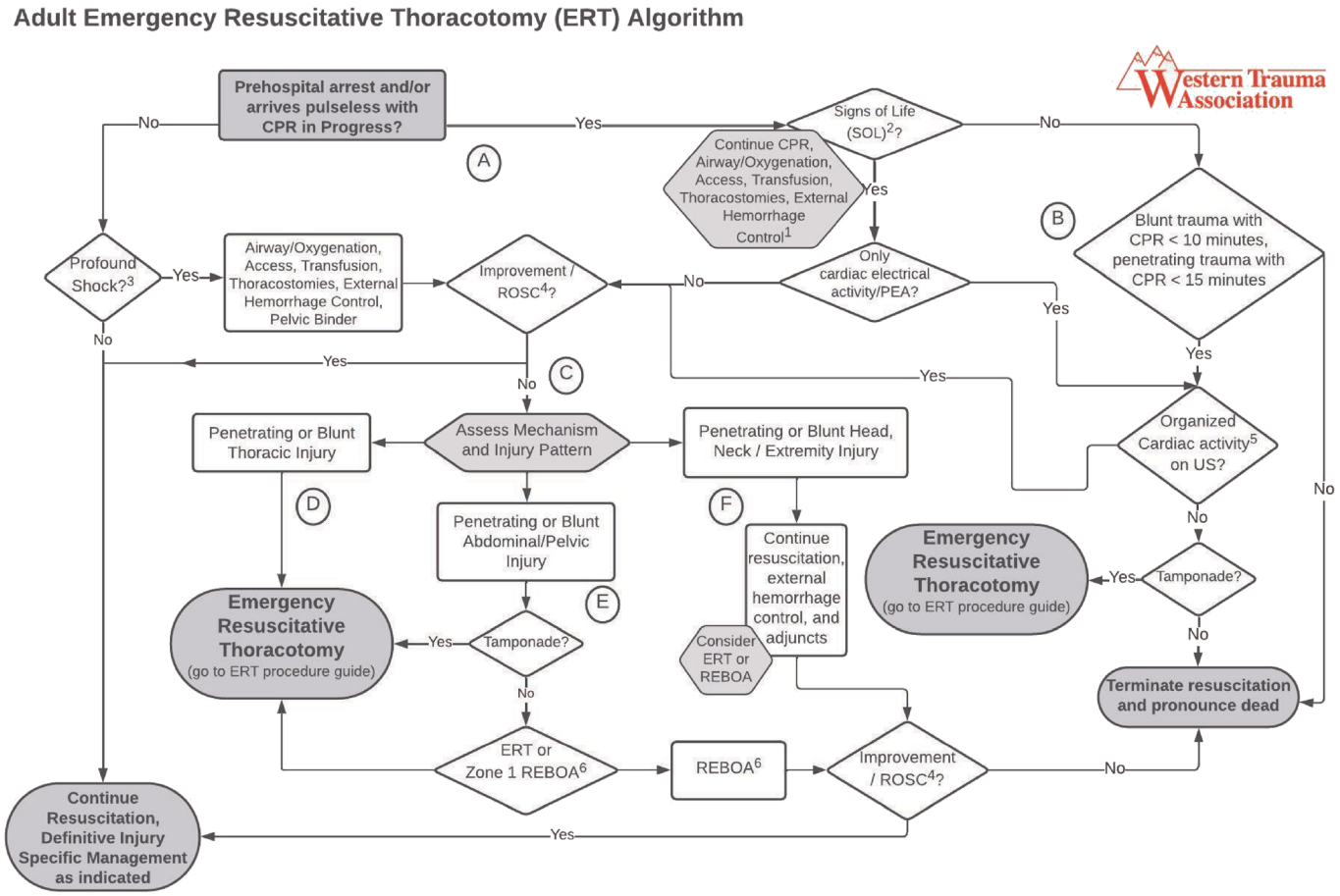

Figure 1. Western Trauma Association adult ERT algorithm. (1) Rapidly establish definitive airway if not done in the field, continue CPR (interruptions in CPR to facilitate resuscitation procedures are acceptable), and obtain vascular access, transfusion, external hemorrhage control, and therapeutic adjuncts when indicated while assessing for signs of life. Do not delay ERT in injury patterns likely to benefit. (2) Signs of life: pupillary response, spontaneous ventilation, presence of pulse or measurable blood pressure, extremity movement, and electrical cardiac activity. (3) Profound shock: SBP < 60 mm Hg. (4) ROSC: Organized cardiac activity and sustained SBP > 70 mm Hg. (5) Organized cardiac activity = organized non-fibrillating cardiac contractions. (6) At surgeon discretion and where available, REBOA may be considered as an alternative for aortic occlusion when no concern for thoracic aortic injury.

section, the recommended step is described in the italicized text after a discussion of evidence and rationale. Clinical decision algorithms are intended to be used as a general framework recognizing that individual patient, institutional, personnel, and situational factors as well as the publication of new research may warrant deviation from and adaptation of the guideline.

ALGORITHM

A: Patient Selection Based on Clinical Status on Arrival and Initial Treatment

Rapid assessment of the patient arriving in extremis after injury to identify easily reversible causes, provide simple lifesaving interventions, and select those who may benefit from ERT and/or aortic occlusion (AO) is the primary objective in the first minutes after arrival. For most patients presenting with profound shock or cardiac arrest after trauma, the cause will be significant hemorrhage. Therefore, hemorrhage control, vascular access, and restoration of intravascular volume should be the priority. Hypoxemia and hypercapnia may rapidly lead to cardiac arrest and adequate oxygenation, and ventilation should be assured. For the patient in cardiac arrest, rapid interventions to treat reversible causes should be performed in an attempt to obtain the return of spontaneous circulation (ROSC) while the patient is assessed for SOL. However, progression to ERT for those with injury mechanism and pattern most likely to benefit from thoracic exploration and control, as described in sections D and E, should not be delayed for adjunctive procedures.[3,8,10–13]

While chest compressions have not been clearly demonstrated to improve outcomes in posttraumatic arrest, they may be helpful in patients who have a source of cardiac arrest other than hemorrhage or whose cause of arrest is suspected to be medical.[14–17] However, in animal models of arrest due to hemorrhagic shock, closed chest compressions (CCC) have failed to demonstrate an improvement in arterial pressure and have been associated with a lower likelihood of ROSC than volume resuscitation alone.[18–20] Although continuation of CCC in traumatic arrest is reasonable, their performance should not impede or delay establishment of intravenous access and volume resuscitation, procedures used to address reversible causes of traumatic cardiac arrest, ERT,

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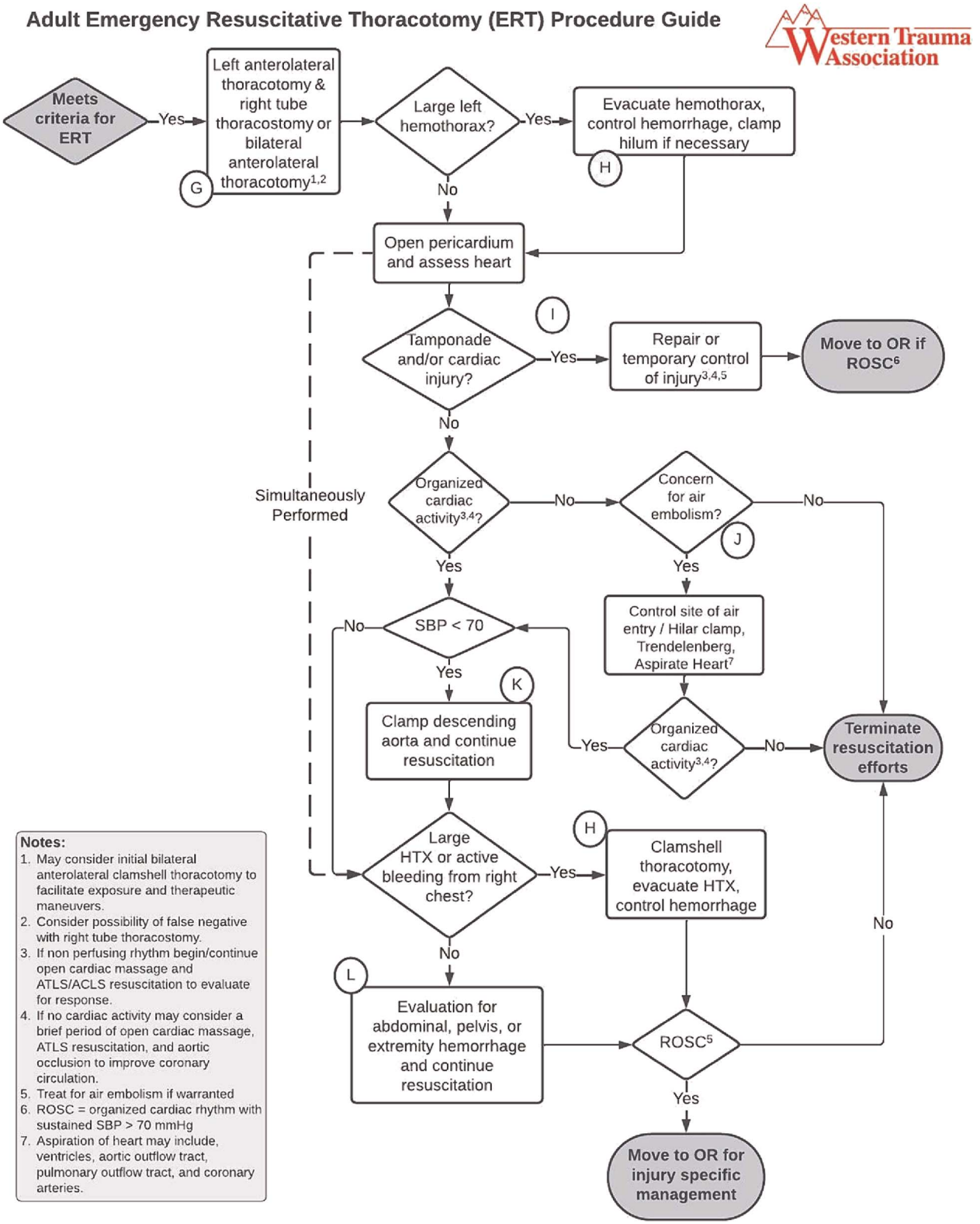
Adult Emergency Resuscitative Thoracotomy (ERT) Procedure Guide
Western Trauma Association
Meets criteria for ERT
Yes
Left anterolateral thoracotomy & right tube thoracostomy or bilateral anterolateral thoracotomy[1,2]
G
Large left hemothorax?
Yes
Evacuate hemothorax, control hemorrhage, clamp hilum if necessary
H
No
Open pericardium and assess heart
Tamponade and/or cardiac injury?
I
Yes
Repair or temporary control of injury[3,4,5]
Move to OR if ROSC[6]
No
Simultaneously Performed
Organized cardiac activity[3,4]?
No
Concern for air embolism?
No
J
Yes
Yes
SBP < 70
No
Control site of air entry / Hilar clamp, Trendelenberg, Aspirate Heart[7]
Yes
K
Clamp descending aorta and continue resuscitation
Organized cardiac activity[3,4]?
Yes
No
Terminate resuscitation efforts
Large HTX or active bleeding from right chest?
H
Yes
Clamshell thoracotomy, evacuate HTX, control hemorrhage
No
No
L
Evaluation for abdominal, pelvis, or extremity hemorrhage and continue resuscitation
ROSC[5]
Yes
Move to OR for injury specific management
Notes:
1. May consider initial bilateral anterolateral clamshell thoracotomy to facilitate exposure and therapeutic maneuvers.
2. Consider possibility of false negative with right tube thoracostomy.
3. If non perfusing rhythm begin/continue open cardiac massage and ATLS/ACLS resuscitation to evaluate for response.
4. If no cardiac activity may consider a brief period of open cardiac massage, ATLS resuscitation, and aortic occlusion to improve coronary circulation.
5. Treat for air embolism if warranted
6. ROSC = organized cardiac rhythm with sustained SBP > 70 mmHg
7. Aspiration of heart may include, ventricles, aortic outflow tract, pulmonary outflow tract, and coronary arteries.

Figure 2. Western Trauma Association adult ERT procedure guide.

or AO. Mechanical compression devices impede access to the chest and if placed by prehospital providers should be removed on arrival to facilitate evaluation and resuscitation procedures.

Emergency resuscitative thoracotomy and AO are not indicated in those with profound shock or cardiac arrest who respond to initial resuscitation and adjunctive treatment with

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ROSC, defined as a perfusing organized cardiac rhythm and a sustained systolic blood pressure of >70 mm Hg. Resuscitation should continue aiming for rapid movement to definitive hemorrhage control and injury specific management.

B: Selection for ERT Based on Signs of Life and Pulseless Cardiac Electrical Activity

The likelihood of neurologically intact survival for those who undergo ERT is impacted by the presence of SOL on arrival, the location and duration of traumatic cardiac arrest (prehospital or in-hospital), and mechanism and pattern of injury.[3,8,10–12,21] The definition of SOL is widely accepted and includes reactive pupillary response, spontaneous movements, spontaneous ventilation, presence of a carotid pulse, measurable or palpable blood pressure, and cardiac electrical activity (CEA).[8,22] Survival for blunt trauma patients presenting without SOL ranges from 0% to 0.7%, while it ranges from 1.6% to 8.3% in penetrating trauma.[3,10,11] The likelihood of neurologically intact survival is higher with penetrating thoracic injury compared with penetrating extrathoracic or blunt injury and is greatest with cardiac stab wounds.[3,4,8,10–12,23] For those presenting without SOL, there seems to be a time signature that predicts futility. A 2011 multicenter study demonstrated survivors of blunt traumatic arrest with up to 9 minutes of cardiopulmonary resuscitation (CPR) and after penetrating trauma with up to 15 minutes of CPR.[4] However, the only survivors in the extremes of these times had evidence of pericardial tamponade. Others have not been able to show survival in blunt trauma when SOL are absent, and the Eastern Association for the Surgery of Trauma guidelines have conditionally recommended not performing ERT for blunt trauma patients without SOL.[8,10,11] Further study is needed to discern whether the defined time limits in penetrating and blunt traumatic injury accurately predicts response to ERT.

Asystole and pulseless cardiac electrical activity (PEA) are the most common rhythms associated with traumatic cardiac arrest and are associated with a poor prognosis.[24–26] Traditionally, SOL have included the presence of CEA.[8,22] While SOL are associated with a survival advantage in traumatic cardiac arrest (11.5% vs. 2.6%), studies have not established whether all signs are equally associated with survival.[3,8,22,27] Many patients with posttraumatic PEA are hypovolemic due to hemorrhage and have low cardiac output rather than cardiac arrest.[25,26] How best to identify patients with PEA or asystole that would benefit from ERT is debatable. In several series, the absence of organized nonfibrillating cardiac contractions on Focused Assessment Using Sonography for Trauma (FAST), even in the presence of CEA, was associated with nonsurvival. In one study, it had a 100% negative predictive value for the identification of survivors and organ donors.[26–28] Cardiac ultrasound can also detect the presence of cardiac tamponade, which is associated with survivors of traumatic cardiac arrest even in the presence of asystole.[4,11,12,27] Many consider wide complex bradycardic electrical activity to be agonal and a sign of nonsalvageabilty; however, this distinction has not been made in most studies.[3,8,22,29] Little is known about survival with a bradycardic rhythm when minimal cardiac contractions are identified on ultrasound. Adequate cardiac windows are difficult to obtain in all patients, with roughly 4% having an indeterminate finding. Cardiac FAST may also be difficult to interpret in patients with asystole and pericardial fluid indicative of tamponade may not be recognized.[27]

When SOL other than CEA are present, a rapid evaluation of response to resuscitation and assessment of mechanism/injury pattern as indicated in section C should occur. In the absence of SOL, blunt trauma patients presenting with greater than 10 minutes and penetrating truncal trauma patients presenting with greater than 15 minutes of prehospital CPR should have resuscitation terminated and be pronounced dead. Those presenting within the described time parameters are considered for ERT. FAST should search for the presence of organized cardiac wall motion or tamponade in patients without SOL and when CEA is the only SOL. Patients with organized wall motion should be rapidly assessed for response to initial resuscitation and mechanism/injury pattern with treatment selection as indicated in section C. Patients with tamponade and asystole should undergo ERT. If cardiac windows are difficult to interpret, consideration for ERT should be made carefully based on mechanism of injury, duration of CPR, and presence of CEA. Patients with absent cardiac wall motion and without tamponade on adequate FAST evaluation should have resuscitation terminated and be pronounced dead.

C: Assessment of Mechanism and Injury Pattern

Patients who fail to respond to rapid initial resuscitation and adjunctive maneuvers and have continued profound shock, SOL, or cardiac wall motion on FAST should be assessed based on their mechanism and pattern of injury to identify those who may benefit from ERT. Injury mechanism and the most affected body region (particularly for severe head trauma) may significantly impact the likelihood of ROSC, survival to discharge, and neurologically intact survival and help inform the decision to proceed with ERT, continue medical resuscitation only, or terminate resuscitation efforts.

D: Penetrating/Blunt Thoracic Injury

Compared with those with extrathoracic injury, survival is improved in patients with penetrating thoracic trauma. Survival as high as 35% for those presenting with shock and isolated cardiac wounds and 15% for all victims of penetrating thoracic trauma has been described.[5,12,30,31] The survival for those presenting with penetrating thoracic trauma and SOL varies from 15% to 23% compared with 2% to 8.3% when SOL are absent.[8,10] These data support the rationale for rapid aggressive ERT in patients presenting with penetrating thoracic trauma who meet criteria. Blunt trauma patients who undergo ERT have significantly worsened survival rates ranging from 0% to 0.7% when SOL are absent to 4.6% when SOL are present.[8,10] Resuscitative endovascular balloon occlusion of the aorta (REBOA) has emerged as an alternative for achieving descending thoracic AO in extrathoracic blunt trauma, and the rationale for its use as an alternative to ERT is discussed in section E. However, those with major thoracic injury may benefit from direct thoracic exploration and hemorrhage control in addition to AO and open cardiac compressions (OCCs), while those with extrathoracic injury are only likely to benefit from the AO and the open compression portions of ERT.

Patients meeting the criteria for ERT who present with penetrating thoracic trauma, penetrating truncal trauma with a

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trajectory concerning for thoracic injury, or obvious blunt thoracic injury should undergo ERT without delay, as they are more likely to have injuries that will benefit from direct control and management through thoracic exploration in addition to OCC and descending thoracic AO.

E: Penetrating or Blunt Abdominal/Pelvic Injury

The management of patients with penetrating or blunt abdominal or pelvic trauma as a cause of traumatic cardiac arrest and profound shock remains an area of controversy. Patients with extrathoracic noncompressible torso hemorrhage have worsened survival compared with those with penetrating thoracic injury.[3–5,8,10] Although penetrating extrathoracic injury fairs better than blunt, appropriately selected patients from both categories have a survival benefit with ERT. The rationale for ERT in these patients is to provide thoracic AO to control infradiaphragmatic hemorrhage and improve cerebral and coronary perfusion while allowing the performance of OCC. However, patients with these injury patterns are unlikely to benefit from the other direct therapeutic thoracic maneuvers that thoracotomy allow.

Open cardiac compression seem to be superior to CCC to salvage patients with traumatic and medical cardiac arrest.[32] Animal models and older human studies have demonstrated superiority of OCC based on measured physiologic variables.[18,33–35] More recently, several studies evaluating end-tidal carbon dioxide in traumatic cardiac arrest have demonstrated improved levels with CCC as compared with OCC, as well as improved ROSC with closed compressions when both methods of compressions were combined with AO.[36,37] Several other studies have reached differing conclusions, and it remains undetermined whether OCC is superior to CCC.[38–40] Closed cardiac compression and OCC may be equivalent when there are alternative methods of AO and no other indications for thoracic exploration.

Balloon occlusion of the aorta for abdominal hemorrhage via the common femoral artery was described in the 1980s, and it has become an integral tool to improve outcomes in ruptured aortic aneurysm.[41–43] Modern applications, miniaturization, and improvement in the technology of REBOA have been developed, and it has emerged as an alternative to ERT in injured patients to control infradiaphragmatic hemorrhage and improve cerebral and coronary perfusion.[43–49] Multiple studies have demonstrated similar outcomes comparing REBOA with ERT in select patient populations.[44–50] Although REBOA would have the highest utility for abdominal, pelvic, and junctional hemorrhage, current data suggest equivalency in select patients with penetrating and blunt chest injuries, and this warrants further evaluation.[49] In contrast to these studies, a nationwide analysis of Trauma Quality Improvement Program (TQIP) data and a recent randomized trial of REBOA versus usual care have demonstrated increased complications, worsened mortality, and prolonged time to hemorrhage control with REBOA, calling into question the utility of the procedure.[51,52] It is likely that proficiency in the procedure related to institutional volume and time to AO impacts the outcomes in REBOA. Resuscitative endovascular balloon occlusion of the aorta (7–8 minutes) is associated with longer duration to successful AO compared with ERT (4–5.2 minutes), although it is unknown whether the few minutes of delay impact outcomes.[50,53] In one study, the overall time to AO was not associated with mortality but may have been impacted by prolonged pre-hospital times.[50] The time limiting step in REBOA is gaining common femoral access, and once obtained, time to AO is more rapid than with ERT.[53] For those who present with profound shock, earlier femoral arterial access is associated with shorter times to AO by REBOA and improved mortality and has been advocated as part of the primary survey in combat casualty care.[54–56] It seems that TQIP is not the ideal source of data to determine REBOA outcomes because of a lack of clinical and hemodynamic granularity.

Patients with penetrating or blunt abdominal/pelvic trauma who present with profound shock or traumatic cardiac arrest should be considered for early femoral arterial access in centers that practice REBOA. A rapid cardiac FAST examination should be performed, and those who have evidence of tamponade should undergo ERT. If tamponade is absent and the injury pattern is not concerning for concomitant thoracic trajectory or blunt aortic injury, REBOA may be considered as an alternative to ERT where training and local expertise exist. For patients selected for REBOA, early transition to ERT should be considered if rapid femoral access is difficult to obtain. Patients who achieve ROSC after Zone 1 AO by REBOA should be rapidly transported to a site where definitive hemorrhage control and injury specific management can occur without delays for diagnostic testing. Where REBOA is unavailable, injury pattern suggests benefit, or when preferred by the surgeon, the patient should undergo ERT. Those who achieve adequate AO and fail to achieve a perfusing organized cardiac rhythm with a systolic blood pressure of >70 mm Hg should have resuscitation terminated and be pronounced dead.

F: Penetrating or Blunt Head/Neck/ Extremity Injury

Patients with isolated penetrating or severe blunt head injury as a cause of profound shock or traumatic cardiac arrest have a high mortality and usually a poor neurologic outcome. Some have advocated for selective use of ERT or REBOA in these patients because of the potential for family visitation or salvage for organ donation.[57–59] A multicenter retrospective study of patients sustaining a gunshot wound to the brain and CPR found a survival to discharge rate of 2.1% with an organ donation rate of 10% among nonsurvivors, but the utilization of ERT in this population was not reported.[60] Given the potential resource, ethical, and health care worker exposure issues, this remains an area of controversy and represents a gap in existing knowledge that will benefit from further research.

Patients who present with isolated penetrating neck or penetrating/blunt extremity injury should undergo continued resuscitation and external hemorrhage control. There are examples of patients with traumatic cardiac arrest after penetrating neck and extremity trauma who survive after ERT, and prior recommendations have been to limit its use to those with CPR less than 5 minutes.[4,5,8,61] It is unclear whether OCC and thoracic AO offer benefit beyond external hemorrhage control, rapid volume restoration, and CCC in most patients. Aortic occlusion also has the potential to worsen hemorrhage in penetrating neck and upper extremity trauma after ROSC.[36–39,62]

Patients with isolated penetrating or severe blunt head injury or penetrating or blunt injury to the neck or extremities who fail to respond to resuscitation and hemorrhage control should have resuscitation terminated and be pronounced dead.

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TABLE 1. Identified Knowledge and Research Gaps in Adult ERT

Subject/Knowledge Deficit	Algorithm Section
1. Identification of criteria for profound shock that portends cardiopulmonary arrest and would benefit from thoracic AO	A
2. Determination of whether closed cardiac compressions are able to improve physiologic parameters and ROSC in hypovolemic traumatic cardiac arrest prior to volume resuscitation and ERT or AO	A
3. Comparison of individual "signs of life" and their ability to predict successful response to ERT	B
4. Identification of whether wide complex bradycardic rhythm <60 with organized cardiac contractions identified on ultrasound would benefit from ERT/AO and continued resuscitation	B
5. Determination of whether defined time limits in penetrating and blunt traumatic injury accurately predict response to ERT or AO	B
6. Determination of whether OCCs have improved ability to achieve ROSC compared with closed cardiac compressions in injury-specific patterns that would not otherwise benefit from direct thoracic exploration.	C
7. Identification of the role of ERT or AO in patients with penetrating or presumed severe blunt brain injury and cardiac arrest to improve survival or conversion to organ donation	E
8. Identification of subgroups of penetrating or blunt extremity and penetrating neck injury that may benefit from ERT or AO versus medical resuscitation and external hemorrhage control	E
9. Delineation of role of REBOA in adult trauma patients in injury-specific patterns	D, E, F
10. Utility and ethics of performing ERT/AO in patient with severe head trauma or without SOL to facilitate potential organ donation	B, C, D, E, F

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Selective use of ERT or REBOA may be considered when the injury pattern suggests the potential for concomitant intracavitary or junctional noncompressible hemorrhage or to facilitate family visitation or salvage for organ donation at the discretion of the treating surgeon.[4,5] *However, performing ERT outside of the currently accepted criteria for these reasons raises ethical, medical, and medicolegal questions. In the absence of any clear national guidelines or consensus on this topic, we suggest that each individual center develop a local policy for handling these cases based on group discussion and consensus.*

PROCEDURE GUIDE

A procedure guide for performance of ERT in the adult patient is included in Figure 2. It is organized in a sequential, stepwise, logical approach to the procedures and order of priorities based on the authors' group consensus. Many steps will be performed simultaneously, and individual wounding characteristics, patient physiology, and response to interventions may lead to appropriate variance in the sequence of events. The corresponding annotated text describing the steps of the procedure can be found in the available Supplemental Digital Content — ERT Procedure Guide — Annotated Text and References (Supplemental Digital Content, Supplementary Data 1, http://links.lww.com/TA/E32).

AREAS OF CONTROVERSY AND EXISTING KNOWLEDGE/RESEARCH GAPS

It important to note that there are many areas of this algorithm that lack high-quality evidentiary support and where further research is required. A list of these areas in need of further research and data generation is provided in Table 1. Even in the areas where we have numerous existing studies and analyses, any conclusions are limited by the overall low quality of existing evidence. Thus, many aspects of this algorithm are based on lower-quality evidence and/or expert opinion and should be thought of as a framework for management but not an absolute dictum for the treatment of any individual patient. Finally, the exact pathways in this algorithm may not be applicable to all settings or centers and, in these cases, should serve as a starting foundation for development of a local algorithm and guideline that is suited to that location and group of trauma surgeons.

SUMMARY AND CONCLUSION

The management of adult trauma patients with profound shock and cardiopulmonary arrest requires rapid nuanced decision making, resuscitation, and procedural intervention including consideration for ERT and AO. The algorithm described in this work represents a rational approach to the selection of patients who would most likely benefit from ERT based on current evidence and expert opinion. Updates from the prior algorithm include the consideration of CEA separately than other SOL and the use of cardiac ultrasound to determine candidacy for ERT in cases where only CEA is present, the introduction of REBOA as a potential alternative to ERT for those with extrathoracic injury, and the removal of a time consideration and deemphasis of ERT for penetrating neck and extremity injury.

Emergency resuscitative thoracotomy should be considered in those with profound shock who fail to respond to resuscitation, those in arrest with SOL other than electrical cardiac activity, for patients with CEA as the only SOL if organized cardiac activity is seen on ultrasound, and in those without SOL presenting within described time parameters with cardiac activity on ultrasound or asystole in the presence of tamponade. Alternative methods of AO and cardiac compressions may be considered in select patients unlikely to benefit from direct thoracic exploration and hemorrhage control.

AUTHORSHIP

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All authors have seen and approved the final manuscript as submitted. The first author (R.T.) had full access to all data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

DISCLOSURE

Conflicts of Interest: Author Disclosure forms have been supplied and are provided as Supplemental Digital Content (http://links.lww.com/TA/E33). Disclaimer: The results and opinions expressed in this article are those of the authors and do not reflect the opinions or official policy of any of the listed affiliated institutions

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REFERENCES

1. Beall AC Jr., Diethrich EB, Cooley DA, DeBakey ME. Surgical management of penetrating cardiovascular trauma. *South Med J*. 1967;60(7):698–704.
2. Moore EE, Moore JB, Galloway AC, Eiseman B. Postinjury thoracotomy in the emergency department: a critical evaluation. *Surgery*. 1979;86(4):590–598.
3. Rhee PM, Acosta J, Bridgeman A, Wang D, Jordan M, Rich N. Survival after emergency department thoracotomy: review of published data from the past 25 years. *J Am Coll Surg*. 2000;190(3):288–298.
4. Moore EE, Knudson MM, Burlew CC, Inaba K, Dicker RA, Biffl WL, et al. Defining the limits of resuscitative emergency department thoracotomy: a contemporary Western Trauma Association perspective. *J Trauma*. 2011; 70(2):334–339.
5. Burlew CC, Moore EE, Moore FA, Coimbra R, McIntyre RC Jr., Davis JW, et al. Western Trauma Association critical decisions in trauma: resuscitative thoracotomy. *J Trauma Acute Care Surg*. 2012;73(6):1359–1363.
6. Seamon MJ, Ginwalla R, Kulp H, Patel J, Pathak AS, Santora TA, et al. HIV and hepatitis in an urban penetrating trauma population: unrecognized and untreated. *J Trauma*. 2011;71(2):306–310; discussion 311.
7. Keller D, Kulp H, Maher Z, Santora TA, Goldberg AJ, Seamon MJ. Life after near death: long-term outcomes of emergency department thoracotomy survivors. *J Trauma Acute Care Surg*. 2013;74(5):1315–1320.
8. Seamon MJ, Haut ER, Van Arendonk K, Barbosa RR, Chiu WC, Dente CJ, et al. An evidence-based approach to patient selection for emergency department thoracotomy: a practice management guideline from the Eastern Association for the Surgery of Trauma. *J Trauma Acute Care Surg*. 2015;79(1): 159–173.
9. Stanford KA, Eller D, Schmitt J, McNulty M, Spiegel T. High rate of HIV among trauma patients participating in routine emergency department screening. *AIDS Behav*. 2023;27(11):3669–3677.
10. DuBose J, Fabian T, Bee T, Moore LJ, Holcomb JB, Brenner M, et al. Contemporary utilization of resuscitative thoracotomy: results from the AAST aortic occlusion for resuscitation in trauma and acute care surgery (AORTA) multicenter registry. *Shock*. 2018;50(4):414–420.
11. Panossian VS, Nederpelt CJ, El Hechi MW, Chang DC, Mendoza AE, Saillant NN, et al. Emergency resuscitative thoracotomy: a nationwide analysis of outcomes and predictors of futility. *J Surg Res*. 2020;255:486–494.
12. Aseni P, Rizzetto F, Grande AM, Bini R, Sammartano F, Vezzulli F, et al. Emergency department resuscitative thoracotomy: indications, surgical procedure and outcome. A narrative review. *Am J Surg*. 2021;221(5):1082–1092.
13. Martin MJ, Brasel KJ, Brown CVR, Hartwell JL, de Moya M, Inaba K, et al. Pediatric emergency resuscitative thoracotomy: a Western Trauma Association, Pediatric Trauma Society, and Eastern Association for the Surgery of Trauma collaborative critical decisions algorithm. *J Trauma Acute Care Surg*. 2023;95(4):583–591.
14. Bohm K, Rosenqvist M, Herlitz J, Hollenberg J, Svensson L. Survival is similar after standard treatment and chest compression only in out-of-hospital bystander cardiopulmonary resuscitation. *Circulation*. 2007;116(25):2908–2912.
15. SOS-KANTO Study Group. Cardiopulmonary resuscitation by bystanders with chest compression only (SOS-KANTO): an observational study. *Lancet*. 2007;369(9565):920–926.
16. Iwami T, Kawamura T, Hiraide A, Berg RA, Hayashi Y, Nishiuchi T, et al. Effectiveness of bystander-initiated cardiac-only resuscitation for patients with out-of-hospital cardiac arrest. *Circulation*. 2007;116(25):2900–2907.
17. Bielski K, Smereka J, Chmielewski J, Pruc M, Chirico F, Gasecka A, et al. Meta-analysis of chest compression-only versus conventional cardiopulmonary resuscitation by bystanders for adult with out-of-hospital cardiac arrest. *Cardiol J*. 2023;30(4):606–613.
18. Luna GK, Pavlin EG, Kirkman T, Copass MK, Rice CL. Hemodynamic effects of external cardiac massage in trauma shock. *J Trauma*. 1989;29(10): 1430–1433.
19. Watts S, Smith JE, Gwyther R, Kirkman E. Closed chest compressions reduce survival in an animal model of haemorrhage-induced traumatic cardiac arrest. *Resuscitation*. 2019;140:37–42.
20. Bethurum A, Smith L, Heidel R, Daley B. 1311: traumatic arrest: the unresolved role of CPR. *Crit Care Med*. 2023;51(1):655.
21. Millin MG, Galvagno SM, Khandker SR, Malki A, Bulger EM, Standards and Clinical Practice Committee of the National Association of EMS Physicians (NAEMSP); Subcommittee on Emergency Services—Prehospital of the American College of Surgeons' Committee on Trauma (ACSCOT). Withholding and termination of resuscitation of adult cardiopulmonary arrest secondary to trauma: resource document to the joint NAEMSP-ACSCOT position statements. *J Trauma Acute Care Surg*. 2013;75(3):459–467.
22. Working Group, Ad Hoc Subcommittee on Outcomes, American College of Surgeons. Committee on Trauma. Practice management guidelines for emergency department thoracotomy. Working group, ad hoc subcommittee on outcomes, American College of Surgeons—Committee on Trauma. *J Am Coll Surg*. 2001;193(3):303–309.
23. Seamon MJ, Shiroff AM, Franco M, Stawicki SP, Molina EJ, Gaughan JP, et al. Emergency department thoracotomy for penetrating injuries of the heart and great vessels: an appraisal of 283 consecutive cases from two urban trauma centers. *J Trauma*. 2009;67(6):1250–1257 discussion 1257-1258.
24. Moriwaki Y, Sugiyama M, Yamamoto T, Tahara Y, Toyoda H, Kosuge T, et al. Outcomes from prehospital cardiac arrest in blunt trauma patients. *World J Surg*. 2011;35(1):34–42.
25. Smith JE, Rickard A, Wise D. Traumatic cardiac arrest. *J R Soc Med*. 2015; 108(1):11–16.
26. Israr S, Cook AD, Chapple KM, Jacobs JV, McGeever KP, Tiffany BR, et al. Pulseless electrical activity following traumatic cardiac arrest: sign of life or death? *Injury*. 2019;50(9):1507–1510.
27. Inaba K, Chouliaras K, Zakaluzny S, Swadron S, Mailhot T, Seif D, et al. FAST ultrasound examination as a predictor of outcomes after resuscitative thoracotomy: a prospective evaluation. *Ann Surg*. 2015;262(3):512–518; discussion 516-518.
28. Cureton EL, Yeung LY, Kwan RO, Miraflor EJ, Sadjadi J, Price DD, et al. The heart of the matter: utility of ultrasound of cardiac activity during traumatic arrest. *J Trauma Acute Care Surg*. 2012;73(1):102–110.
29. Battistella FD, Nugent W, Owings JT, Anderson JT. Field triage of the pulseless trauma patient. *Arch Surg*. 1999;134(7):742–745; discussion 745-746.
30. Nevins EJ, Bird NTE, Malik HZ, Mercer SJ, Shahzad K, Lunevicius R, et al. A systematic review of 3251 emergency department thoracotomies: is it time for a national database? *Eur J Trauma Emerg Surg*. 2019;45(2):231–243.
31. Hughes M, Perkins Z. Outcomes following resuscitative thoracotomy for abdominal exsanguination, a systematic review. *Scand J Trauma Resusc Emerg Med*. 2020;28(1):9.
32. Benson DM, O'Neil B, Kakish E, Erpelding J, Alousi S, Mason R, et al. Open-chest CPR improves survival and neurologic outcome following cardiac arrest. *Resuscitation*. 2005;64(2):209–217.
33. Boczar ME, Howard MA, Rivers EP, Martin GB, Horst HM, Lewandowski C, et al. A technique revisited: hemodynamic comparison of closed- and open-chest cardiac massage during human cardiopulmonary resuscitation. *Crit Care Med*. 1995;23(3):498–503.
34. Rubertsson S, Grenvik A, Wiklund L. Blood flow and perfusion pressure during open-chest versus closed-chest cardiopulmonary resuscitation in pigs. *Crit Care Med*. 1995;23(4):715–725.
35. Martin GB, Carden DL, Nowak RM, Tomlanovich MC. Comparison of central venous and arterial pH and PCO2 during open-chest CPR in the canine model. *Ann Emerg Med*. 1985;14(6):529–533.
36. Bradley MJ, Bonds BW, Chang L, Yang S, Hu P, Li HC, et al. Open chest cardiac massage offers no benefit over closed chest compressions in patients with traumatic cardiac arrest. *J Trauma Acute Care Surg*. 2016;81(5):849–854.
37. Teeter WA, Bradley MJ, Romagnoli A, Hu P, Li Y, Stein DM, et al. Treatment effect or effective treatment? Cardiac compression fraction and end-tidal carbon dioxide are higher in patients resuscitative endovascular balloon occlusion of the aorta compared with resuscitative thoracotomy and open-chest cardiac massage. *Am Surg*. 2018;84(10):1691–1695.
38. Endo A, Shiraishi A, Otomo Y, Tomita M, Matsui H, Murata K. Open-chest versus closed-chest cardiopulmonary resuscitation in blunt trauma: analysis of a nationwide trauma registry. *Crit Care*. 2017;21(1):169.
39. Endo A, Kojima M, Hong ZJ, Otomo Y, Coimbra R. Open-chest versus closed-chest cardiopulmonary resuscitation in trauma patients with signs of life upon hospital arrival: a retrospective multicenter study. *Crit Care*. 2020;24(1):541.

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40. Wang M, Lu X, Gong P, Zhong Y, Gong D, Song Y. Open-chest cardiopulmonary resuscitation versus closed-chest cardiopulmonary resuscitation in patients with cardiac arrest: a systematic review and meta-analysis. *Scand J Trauma Resusc Emerg Med*. 2019;27(1):116.
41. Hughes CW. Use if intra-aortic balloon catheter tamponade for controlling intra-abdominal hemorrhage in man. *Surgery.* 1954;36:65–68.
42. Gupta BK, Khaneja SC, Flores L, Eastlick L, Longmore W, Shaftan GW. The role of intra-aortic balloon occlusion in penetrating abdominal trauma. *J Trauma*. 1989;29(6):861–865.
43. Borger van der Burg BLS, van Dongen TTCF, Morrison JJ, Hedeman Joosten PPA, DuBose JJ, Hörer TM, et al. A systematic review and meta-analysis of the use of resuscitative endovascular balloon occlusion of the aorta in the management of major exsanguination. *Eur J Trauma Emerg Surg*. 2018;44(4):535–550.
44. Brenner M, Inaba K, Aiolfi A, DuBose J, Fabian T, Bee T, et al. Resuscitative endovascular balloon occlusion of the aorta and resuscitative thoracotomy in select patients with hemorrhagic shock: early results from the American Association for the Surgery of Trauma's aortic occlusion in resuscitation for trauma and acute care surgery registry. *J Am Coll Surg*. 2018;226(5):730–740.
45. Manzano Nunez R, Naranjo MP, Foianini E, Ferrada P, Rincon E, García-Perdomo HA, et al. A meta-analysis of resuscitative endovascular balloon occlusion of the aorta (REBOA) or open aortic cross-clamping by resuscitative thoracotomy in non-compressible torso hemorrhage patients. *World J Emerg Surg*. 2017;12:30.
46. Bini JK, Hardman C, Morrison J, Scalea TM, Moore LJ, Podbielski JM, et al. Survival benefit for pelvic trauma patients undergoing resuscitative endovascular balloon occlusion of the aorta: results of the AAST aortic occlusion for resuscitation in trauma acute care surgery (AORTA) registry. *Injury.* 2022;53(6):2126–2132.
47. Granieri S, Frassini S, Cimbanassi S, Bonomi A, Paleino S, Lomaglio L, et al. Impact of resuscitative endovascular balloon occlusion of the aorta (REBOA) in traumatic abdominal and pelvic exsanguination: a systematic review and meta-analysis. *Eur J Trauma Emerg Surg*. 2022;48(5):3561–3574.
48. DuBose JJ, Scalea TM, Brenner M, Skiada D, Inaba K, Cannon J, et al. The AAST prospective aortic occlusion for resuscitation in trauma and acute care surgery (AORTA) registry: data on contemporary utilization and outcomes of aortic occlusion and resuscitative balloon occlusion of the aorta (REBOA). *J Trauma Acute Care Surg*. 2016;81(3):409–419.
49. Cralley AL, Vigneshwar N, Moore EE, Dubose J, Brenner ML, Sauaia A, AAST AORTA Study Group. Zone 1 endovascular balloon occlusion of the aorta vs resuscitative thoracotomy for patient resuscitation after severe hemorrhagic shock. *JAMA Surg*. 2023;158(2):140–150.
50. Koh EY, Fox EE, Wade CE, Scalea TM, Fox CJ, Moore EE, et al. Resuscitative endovascular balloon occlusion of the aorta and resuscitative thoracotomy are associated with similar outcomes in traumatic cardiac arrest. *J Trauma Acute Care Surg*. 2023;95(6):912–917.
51. Joseph B, Zeeshan M, Sakran JV, Hamidi M, Kulvatunyou N, Khan M, et al. Nationwide analysis of resuscitative endovascular balloon occlusion of the aorta in civilian trauma. *JAMA Surg*. 2019;154(6):500–508.
52. Jansen JO, Hudson J, Cochran C, MacLennan G, Lendrum R, Sadek S, et al. Emergency department resuscitative endovascular balloon occlusion of the aorta in trauma patients with exsanguinating hemorrhage: the UK-REBOA randomized clinical trial. *JAMA*. 2023;330(19):1862–1871.
53. Romagnoli A, Teeter W, Pasley J, Hu P, Hoehn M, Stein D, et al. Time to aortic occlusion: it's all about access. *J Trauma Acute Care Surg*. 2017;83(6):1161–1164.
54. Matsumura Y, Matsumoto J, Kondo H, Idoguchi K, Ishida T, Okada Y, et al. Early arterial access for resuscitative endovascular balloon occlusion of the aorta is related to survival outcome in trauma. *J Trauma Acute Care Surg*. 2018;85(3):507–511.
55. Knipp BS, Needham KE, Nguyen PT, Keville MP, Brzuchalski JT, Srivilasa C, et al. Leaning forward: early arterial access promotes resuscitative endovascular balloon occlusion of the aorta utilization in battlefield casualties. *J Trauma Acute Care Surg*. 2020;89(2S Suppl 2):S88–S92.
56. Stokes SC, Theodorou CM, Zakaluzny SA, DuBose JJ, Russo RM. Resuscitative endovascular balloon occlusion of the aorta in combat casualties: the past, present, and future. *J Trauma Acute Care Surg*. 2021;91(2S Suppl 2):S56–S64.
57. Schnüriger B, Inaba K, Branco BC, Salim A, Russell K, Lam L, et al. Organ donation: an important outcome after resuscitative thoracotomy. *J Am Coll Surg*. 2010;211(4):450–455.
58. Raoof M, Joseph BA, Friese RS, Kulvatunyou N, O'Keeffe T, Tang A, et al. Organ donation after traumatic cardiopulmonary arrest. *Am J Surg*. 2011;202(6):701–705; discussion 705-706.
59. Love KM, Brown JB, Harbrecht BG, Muldoon SB, Miller KR, Benns MV, et al. Organ donation as an outcome of traumatic cardiopulmonary arrest: a cost evaluation. *J Trauma Acute Care Surg*. 2016;80(5):792–798.
60. Robinson LA, Turco LM, Robinson B, Corsa JG, Mount M, Hamrick AV, et al. Outcomes in patients with gunshot wounds to the brain. *Trauma Surg Acute Care Open*. 2019;4(1):e000351.
61. Sheppard FR, Cothren CC, Moore EE, Orfanakis A, Ciesla DJ, Johnson JL, et al. Emergency department resuscitative thoracotomy for nontorso injuries. *Surgery.* 2006;139(4):574–576.
62. Simpson C, Tucker H, Hudson A. Pre-hospital management of penetrating neck injuries: a scoping review of current evidence and guidance. *Scand J Trauma Resusc Emerg Med*. 2021;29(1):137.

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